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A SYSTEMATIC SOURCE OF EVOLUTION OF PROVINCIAL FAUNAS.

THE deformations of the outer portion of the solid part of the earth familiarly known as the "crust" are the result of an intricate combination of adventitious and systematic movements. The latter spring from the predominant action of the great stresses that affect the body of the earth; the former, from intercurrent variations in the expression of these dominant agencies due primarily to the rigidity of the earth, and secondarily to inequalities in its density, to changes in its internal temperature, and perhaps to other conditions. Were the earth a homogeneous liquid, the adventitious features would disappear and all its changes of form would be systematic, or if not absolutely all, at least all which seriously affect its deformation. While the adventitious movements that make for heterogeneity of configuration must be recognized, it is the function of the geologist to discriminate and emphasize the systematic factors and to relegate the adventitious elements to their proper subordination.

It is assumed that the fundamental movements which affect the earth's form are centripetal and that the dominant fact in the bodily history of the earth is the shrinkage of its outer parts, as has been so signally urged by Suess. Its upward movements may be regarded as adventitious, since they are incidents due to the restraint which rigidity puts upon a perfect adjustment to the demands of its contractile forces, or to variations from symmetry of substance or of temperature which only become effective through its rigidity. In a slightly different and broader sense, the continents may be said to be adventitious while the ocean basins may be said to be normal. We must hasten, however, to qualify this idea, for the ocean basins have obviously sunk beyond the normal level which the surface of the earth would assume, did not rigidity deform it. The uniform spher-

oidal surface to which an ideal earth would be adjusted lies about 9000 feet below the ocean surface.[1] The portions of the ocean basin below this normal level represent an excess of shrinkage. The continental masses which stand above this average level represent a deficiency in shrinkage. This average level is the natural datum plane from which the continents may be conceived to rise. The ideal upper surface of a continent may be said to be the sea level, a plane which the upper surface of the continent constantly approaches but never entirely reaches. That portion of it which is exposed above the sea level undergoes constant truncation by air and water. The portion beneath the sea level is being constantly built up by the deposition of land wash about its borders, forming a sea shelf whose summit plane is the sea level.[2] As a result of these activities, continued throughout the ages, the continents have come to be approximate platforms whose theoretical upper horizon is the sea level. To this they are accommodated more or less approximately, but never perfectly. They reach their most complete adjustment after long intervals of relative quiescence, when base-leveling attains its highest degree of perfection. They depart most widely from the theoretical surface at the climax of great periods of crustal readjustment to accumulated internal stresses. Such periods of greatest departure inaugurate periods of maximum activity, both on the part of the leveling forces, whose function it is to reduce the land surface again to the sea level, and on the part of the depositional agencies whose function it is to build up a sea-shelf around the borders of the continent. In other words, agencies for the replanation of the platform are put into maximum activity by the very agency which deformed it. If we conceive the continental platform to be the basal portion of a broad truncated pyramid whose bottom rests upon the ideal average level, 9000 feet below the sea surface, and whose truncated summit is ideally at the sea level, it

[1] GILBERT, Article "Earth," Johnson's Cyclopædia.

[2] See "The Ulterior Basis of Time Divisions and the Classification of Geologic History," JOUR. GEOL., Vol. VI, No. 5, 1898, pp. 449–462.

may be said that the widest departure of the average land surface from this ideal summit level has probably at no time exceeded 25 or 30 per cent. of the whole height of the platform, while at times of greatest approximation to the theoretical summit level through base leveling, its departure has probably not reached 10 per cent. of the whole height of the platform. The conception of a continent, therefore, as a platform maintained against deforming agencies by constant truncation of the protruding portions and by constant upbuilding about its borders is not seriously vitiated by the inequalities which crustal readjustments force upon it from time to time.

The ocean basins, considered as inverted plateaus or anti-plateaus, have no analagous agency for the reduction of their bottoms to an ideal plain, and their inequalities are greater (in their broad features, but not in detailed accentuation), and yet here is a reasonable approximation to a bottom plain, for more than half of the oceanic bottom lies between 12,000 and 18,000 feet below sea level. But the variation of 6000 feet included between these limits would be regarded as very large if it were a land surface.

More or less warping of the surface of the solid part of the earth is doubtless in progress at all times, but there is much concurrent geologic evidence to the effect that the really mportant changes are periodic rather than uniformly progressive. The most important items in this evidence arc the great base levels and the great epochs of mountain making, the former pointing to long periods of relative quiescence, the latter to exceptional periods of disturbance. In the larger conceptions of the earth movements, the minor warpings may be ignored, but in the interpretation of the details of the earth's history they play a not unimportant part. The degree of importance of this part is dependent upon the critical relationships which the warping may bear to sea-level relations. The present study is concerned with such relationships in their bearing upon the progress of marine life.

The discussion proceeds upon the following general concep-

tions: (1) The continents are platforms whose summits are accommodated approximately to the sea level by truncation and by concurrent circumjacent filling. (2) The normal and the dominant feature of each readjustment of the outer part of the crust to internal contractional stresses is the sinking of the ocean basins and the enlargement of their capacity. (3) The incidental consequence of the sinking of the oceanic basins is the withdrawal into them of an increased amount of the epicontinental waters and the establishment of a new shore line upon the borders of the continent lying at a lower level than the preceding one. (4) The main readjustments are periodic and are separated by intervening stages of relative quiescence. (5) The continental platforms are subject to warping, partly due to the lateral thrust of segments of the earth as they sink (especially those segments that lie beneath the ocean), partly to internal changes of temperature and the intrusion of liquid matter, and partly to the settling of the continent when, by any of the preceding agencies it has been forced upward beyond the plane of isostatic equilibrium, the settling being accomplished through the slow quasi-fluid creep of the rock under gravitative stress.

As a mode of approach to the critical attitudes of sea and land which favor the evolution of provincial faunas, two more general and systematic attitudes which favor respectively general expansional evolution and general contractional evolution may be considered.[1]

1. *Conditions favorable to general expansional evolution of marine life.*— It is to be understood that only that element of marine life is here considered which has for its habitat the relatively shallow sea water adjacent to the land. Geologically speaking we know very little respecting the true abysmal life of the past, and only such little about the surface pelagic life as became incidentally involved in the terrigenous deposits. In considering the shallow-water life adjacent to the land we are, therefore, considering practically that phase of marine life which alone enters effectively into the geologic record. The conditions

[1] These were discussed on pp. 454–459 of preceding number of this JOURNAL.

favorable to an expansional evolution of this shallow-water marine life are those which ensued upon a protracted period of base leveling.[1] This, by its very terms, implies a protracted period of freedom from great movements on the part of the land or the sea. At the climax of such a period there is normally an extensive transgression of the sea upon the continental platform which assumes two phases: (1) the development of broad sea-shelves by the cutting back landward of the sea cliff and the building out seaward of the submarine sea terrace by means of the land detritus; (2) the creeping of the sea waters far inland upon the lower portions of the continent.

At first thought it may be questioned whether the land will not be *extended* by the addition of detritus to its border, and, still further, whether the transgression of the sea is genetically connected with base leveling and is its normal attendant. That the land is now being extended in certain places by detrital accretions to its borders, as in the case of deltas, is beyond question, but it is equally beyond question that the sea is advancing in other places, and it will probably be apparent, after a careful inspection of the continental coasts, that on the average the sea is advancing rather than retiring. But the present is far removed from a base-level period. The streams carry to the sea much more detritus than they would were the surface closely approaching a base level. The sea also, it is to be admitted, is better able to carry detritus back to deep water under present conditions than it would be if its sea-shelf were greatly extended. Conclusions drawn from present conditions are, therefore, embarrassed to this extent on both sides. The issue is really a contest between the ability of the streams to deliver detritus at the coast line and the ability of the sea to carry it back to deep water. The delivery of the streams is a declining factor which approaches zero as the base level is approached. The carrying ability of the sea is much more

[1] A suitable sinking of the land independent of base leveling may produce similar though not quite identical results, but in so far as this is adventitious it does not fall into the category under discussion here.

nearly constant. It is reduced, indeed, by the growing width of the sea-shelf. But the growth of the sea-shelf on its abysmal border must necessarily be slow because of the great depth to be filled, and hence, unless the shelf grows inland, its extension is relatively slight and the ability of the sea to dispose of the detritus borne into it remains nearly constant. With the inevitable decline in the delivery of land wash, as base level is approached, the disposing power of the sea must gain the ascendancy. It would seem to be almost obvious that if there were no movements of the crust for an indefinite period the ultimate result must be the complete truncation of the land to a level below the effective reach of the waves.

But the case does not rest simply with the results of the contest between the diminishing stream action and the nearly constant wave action. There are two supplementary factors which aid the latter. (1) The deposit of the detritus of the land in the sea raises its level. If the average elevation of the present land be taken at Lapparent's figures, 2120 feet, its truncation and removal to the ocean would lift the sea level 700 feet (making no allowance for the spread of the sea). This would certainly be effective in advancing the sea upon the land. (2) The continents after the relative upthrusts attendant upon crustal readjustment probably stand on the average above the plane of isostatic equilibrium, as indicated in the existing status by pendulum observations. From this they should settle back toward equilibrium by virtue of the quasi-fluency of the rocks. The effects of this might, perhaps, decline as erosion proceeded, but the shifting of the load to the borders of the continent would probably aid in depressing them and facilitating the advance of the sea.

The inland extensions of the sea attendant upon such an advance may be conveniently designated epicontinental seas. The great sea which lies between Europe and Africa is properly termed a mediterranean sea, since it really lies between the continents in a deep basin descending to depths of 6000 feet and more. But the seas here referred to as epicontinental are not

of this kind, but are such as are formed by the creeping out upon the low parts of the land of a film of the sea, as it were. The North and the Baltic seas, the Gulf of St. Lawrence and Hudson's Bay are adventitious examples.

It is obvious that at a stage when the sea-shelves and the epicontinental seas were thus extending themselves the conditions for the expansional evolution of shallow-water marine life were signally favorable. In so far as land detritus is inimical to such life, an additional favoring factor is found in the reduction of the surface relief and the consequent diminution of the land wash. The seas at such stages were being not only extended but progressively clarified. A further incident of such stages is the free intercommunication of the life. All of the great continents are at present connected by submerged portions of their platforms and appear to have been so united from the Cambrian times onward. Europe is connected with Greenland by a shallow tract, embracing Iceland, and Greenland, in turn, with the Arctic islands, and thence with the northeastern part of the American continent, constituting a northwest passage for European shallow-water life. On the other hand, Asia is connected by a tract underlying Behring Sea and Straits, and by a broad belt along the border of the Arctic Ocean of unknown width, constituting a northeastern passage for Eurasian life. At times of base leveling there are broad sea-shelves girdling all of the continents, as well as internal epicontinental seas affording other connections; so that altogether the facilities for the migration and the intercommingling of the faunas are exceptionally propitious.

At the same time, as I have endeavored to show in another article in this number,[1] the atmospheric and climatic conditions are uniform and favorable to the widest distribution of life.

In such a period, therefore, is to be found the climax of conditions favorable to expansional evolution and to the development of a world-wide fauna of a composite and comprehensive

[1] The Effects of Great Limestone-forming Epochs upon the Constitution of the Atmosphere, pp. 609.

type. Such faunas appear to characterize the Middle Silurian, the Middle Ordovician, the Carboniferous, and the Cretaceous periods, and in a less pronounced degree the Devonian, the Jurassic, and the early Tertiary.

(2) *Conditions imposing general restrictional evolution of marine life.*—If at the close of a period of great base leveling attended by expansional evolution of marine life, as just outlined, an epoch of profound readjustment to the earth's accumulated contractional stresses ensues, the great feature of which consists of the sinking of the ocean basins or some large part of them, the effect is to withdraw the waters from the surface of the continental platforms into the basins thus increased in capacity and to establish a new shore line somewhere near the edge of the continental platforms. If the enlargement of the capacities of the ocean basins is pronounced, a new shore line may be established, not upon the upper face of the continental platforms, but upon their abysmal slopes. In this case the shallow-water belt will be narrow and will consist of a rapidly shelving shore tract. It is obvious that the great expansional fauna which has occupied the broad sea-shelves and the extended epicontinental seas of the preceding period will be compelled to follow the retiring sea and crowd itself into this restricted zone on the abysmal slope of the continents. It is further obvious that, in addition to the restricted area into which the fauna is thus forced, the new conditions will be in many respects uncongenial, for the streams will be rejuvenated and the amount of land wash will be greatly increased. Those species whose existence is dependent upon clear seas will be in imminent danger of extinction. Certain species to which these conditions are congenial may on the other hand be favored, but the grand result must necessarily be the destruction of the larger part of the previous expansional fauna and the forced adaptation of the remainder to new, and on the whole sterile and hostile conditions. A stage of general repressional evolution is thereby inaugurated and, in a comparatively short period, it is safe to assume, all or nearly all preceding species will have passed out of existence and new species,

in a much more limited number but better adapted to the new conditions, will have been introduced. Such restrictive conditions appear to have been prevalent in a pronounced degree at the close of the Palæozoic era and less notably at the close of the Ordovician period and at other times. But in neither of these cases were the repressional conditions complete, and it is improbable that the ideal conditions of repression here sketched were ever fully realized.

(3) *Conditions favorable to the evolution of provincial faunas.*— It is obvious that if the sea shore be drawn far down the abysmal slope of the ideal sea-shelf, moderate warpings of the continental platform will have little or no effect upon the conditions of faunal development, for whether the shore stands high or low upon this abysmal face the shallow-water tract will remain a mere ribbon. But if, on the other hand, the sea be withdrawn merely to the angle of the sea-shelf the relations between sea and land will be critical and every warping of the surface platform will be decisive either in emphasizing the restrictional influence or in relieving it. To illustrate by a specific case: suppose the sea level to lie accurately at the angle of the ideal sea-shelf, and that portions of the continental platform are warped upward to the amount of 500 feet, while alternating portions are warped downward to an equal amount. The shore line in the former case will lie along the abysmal face and the shallow-water tract will be narrow. In the latter case the shore line will be thrown out upon the upper surface of the sea-shelf and the shallow-water tract will be relatively wide. If the sea-shelf be ideal its upper surface will have a very gentle slope and the downward warping of 500 feet would carry the shore line well inland and give a notable embayment favorable to the perpetration and development of shallow-water life. Under such conditions of alternate warping up and down the continental platform would be bordered by embayments favorable to life, separated by narrow shore tracts which would be largely prohibitive of free migration of shallow-water life between the embayments. Each embayment will there-

fore develop its fauna in measurable independence. Each embayment will become the generating area of a provincial fauna. If now a period of quiescence ensues and systematic continental evolution proceeds, these embayments will become extended landward and grow into extensive epicontinental gulfs and perhaps at length into broad epicontinental seas, and their faunas will expand accordingly. In the progress of this development they may come into conjunction with each other and a commingling and conflict of faunas ensue, resulting in the evolution of a new assemblage of life of a composite type.

Whether the internal progression reaches this stage or not, the development of the sea-shelves must at length attain a stage such that coastal migration will become free and the faunas of the embayments become commingled by coastwise extension. The ideal result of this line of progression is the evolution at length of a general fauna of the expansional type and the concurrent elimination or fusion of the provincial features, for the line of progress is essentially expansional, and the result is expansional evolution. It differs only from an expansional evolution starting from a general restrictional evolution in the commingling and conflict of well-differentiated faunas resulting from provincial development.

At the close of the Silurian period the sea appears to have been drawn away from the land into the critical attitude here indicated, and the basin of the St. Lawrence Gulf and probably that of Hudson's Bay and perhaps other embayments on the borders of the continent, appear to have furnished refuges for the retiring fauna of the Silurian period, and to have become areas in which the origination of provincial faunas took place. The consecutive series of sediments of the St. Lawrence embayment, though not yet perfectly investigated, give good grounds for the belief that the transition of the Silurian fauna into the Helderberg fauna took place there. After its provincial character had been fully assumed and the re-advance of the sea opened the way into the interior through the Champlain tract, it reinvaded the interior basin and left its record as a distinctive

fauna. It was followed in succession by the invasion of the Oriskany fauna, whose place of origin is less clear, but which followed the Helderberg track; by the Corniferous fauna, apparently from the Hudson's Bay embayment; by the early Hamilton fauna, apparently from some southern embayment; and by the later Hamilton fauna, apparently from the Mackenzie embayment, or beyond, thus giving to the Devonian period a distinctive aspect as a time of successive invasions of provincial faunas generated in embayments about the borders of the continent.[1] Had the waters been withdrawn so far as to have emptied these embayments, as was apparently the case at the close of the Palæozoic era, a general repressional evolution would have taken the place of this pronounced provincial evolution. The determinative element, therefore, seems to have been *the critical attitude of the sea to the land* which gave maximum effect to the inequalities of its border.

It is obvious that any previous warping of the continental platform by which a portion of it is submerged may give rise to an embayment covered by relatively shallow water at times of the ocean's withdrawal, and that this may become a refuge for the retreating faunas, and may break the force of the general repressional evolution which would otherwise ensue. This may take place even when the seas are withdrawn down to a level much below the critical horizon just discussed. Such embayments may be regarded as adventitious, since they are not the product of the systematic actions here discussed. But such adventitious embayments were probably always present at times of great withdrawals of the sea, and so broke the force of repressional evolution. In the withdrawal of the sea at the close of the Palæozoic era, the Mediterranean basin appears to have afforded such a retreat for the hard-pressed Permian life of the western part of the Eurasian continent, and to have become a transitional tract in which originated one of the three or four great provincial faunas that advanced upon the land in the Triassic and Jurassic periods. A similar great embayment appears to have existed in

[1] Drawn mainly from the studies of H. S. Williams and Stuart Weller.

the upper Indus and Ganges basins, involving the site of the present Himalayas, and this appears to have been preëminently a transition tract from the Palæozoic to the Mesozoic eras.[1] The adventitious factor in such cases becomes a saving clause so far as the efficient preservation of remnants of the previous fauna is concerned. But even the adventitious factors receive their importance from their critical relations to the systematic attitudes of land and sea upon which chiefly depend the great lines of progress of marine life.

T. C. CHAMBERLIN.

[1] GRIESBACH, Mem. Geol. Surv. India, Vol. XVIII, pp. 1–232, 1891.